

Project	AtlantOS – 633211
Deliverable number	2.4
Deliverable title	SOOP Network Enhancement Report
Description	Report on the network enhancement project, this will document (a) extension of network coverage to South Atlantic; (b) evaluation of improved EOVS carbonate system; and (c) re-assessment of instrumentation
Work Package number	WP 2, Task 2.2
Work Package title	Enhancement of Ship Based Observing Networks
Lead beneficiary	UNEXE
Lead authors	Professor Andrew Watson
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Submission data	
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Comments	



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Stakeholder engagement relating to this task*

WHO are your most important stakeholders?	<input type="checkbox"/> Private company If yes, is it an SME <input type="checkbox"/> or a large company <input type="checkbox"/> ? <input checked="" type="checkbox"/> National governmental body <input type="checkbox"/> International organization <input type="checkbox"/> NGO <input checked="" type="checkbox"/> others Please give the name(s) of the stakeholder(s): university, IRD, CNRS, NERC, ICOS, IOCCP
WHERE is/are the company(ies) or organization(s) from?	<input checked="" type="checkbox"/> Your own country <input checked="" type="checkbox"/> Another country in the EU <input type="checkbox"/> Another country outside the EU Please name the country(ies): ... UK and within Europe
Is this deliverable a success story? If yes, why? If not, why?	<input checked="" type="checkbox"/> Yes Even if we are having difficulties in extending into the Southern Ocean, our network is making advances and future collaborations with the shipping industry seem positive. All other objectives have been successfully met.
Will this deliverable be used? If yes, who will use it? If not, why will it not be used?	<input checked="" type="checkbox"/> Yes, by other scientists, researchers, institutes and industry

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult [D10.5](#) Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.

Deliverable D2.4: SOOP Network Enhancement Report

Background to Task 2.2 Ships of Opportunity Program (SOOP)

The task aims to improve the coherence and coordination, coverage, quality, timeliness and data flow from the existing, formerly uncoordinated ship of opportunity networks (Carbon-VOS, SOOP and FerryBox). The task objectives are to enhance the 3 networks by: extending them throughout the South Atlantic [NERC, CNRS, IRD, PLOCAN]; by adding and supporting routes; exchange information on sampling and sampling design; improve the network instrumentation by re-assessing instrument design [PML]; add a key carbonate system EOVS - an autonomous flow-through system for TA [GEOMAR, CONTROS, PLOCAN].

The network of SOOP ships currently working in the North Atlantic provides a backbone of essential basin-wide observations of physical and biogeochemical parameters that cannot be measured by other means, including carbon parameters and nutrients, as well as SST and SSS ground-truth. These measurements enable for example monthly resolution of the net North Atlantic Ocean-atmosphere CO₂ flux, accurate to better than 20% when integrated with ARGO, satellite and physical re-analysis data, provided that coverage is coherent and well-coordinated. However, at the start of AtlantOS the three observation networks (Carbon-VOS, FerryBox, SOOP) were not co-ordinated. The aim is to improve connectivity of these networks in terms of infrastructure, data standards, protocols, and utility for development of products. Currently the three networks are operated separately and potential synergies that could arise, e.g., sharing platforms, expertise, providing a continuum of observations for key EOVSs from the open ocean into the coastal realm, or cross-fertilization for data products are missed. This task will therefore pave the way for future realisation of such synergies from harmonized and concerted networks.

In this deliverable we report below on three topics: (a) progress in extending coverage of the network (b) evaluation of progress on evaluating instrumentation for an additional EOVS, namely Total Alkalinity, suitable for the SOOP, and (c) evaluation of new types of instrumentation for pCO₂ analysis for the SOOP.

(a) Support of North Atlantic work and extension of network coverage to the South Atlantic: NERC (participant no. 2), CNRS (participant no. 6), IRD (participant no. 25), PLOCAN (participant no. 15).

SUMMARY:

There has been success in maintaining the existing network and some extension to the South Atlantic. However, a major issue for our observation effort is that rapid changes in the shipping industry are negatively impacting the SOOP network: whereas historically, vessels were usually committed to routes for extended periods, this is rapidly becoming a rarity, with the industry moving to general purpose container vessels that change routes continuously. The frequent changes in routes make it very difficult to maintain an observing network with regular time series on a given route, due to the labour and costs associated with continually re-installing scientific instruments on board vessels for short periods of time. The successful routes on which it is proving possible to sustain time series are mostly vessels operated for strategic, rather than purely commercial, reasons. For example, two of the most reliable routes are from Denmark to Greenland (AX01) operated by the Royal Arctic line under a long-term contract with the government of Greenland, and the MN Colibri (France-French Guiana line), which is a specialist ship built to transport rocket components.

We have found it especially difficult to locate available vessels that run for extended periods through the South Atlantic Ocean. The current (March 2018) status of the coverage in the South Atlantic is: (1) A regular line France-Brazil is running (IRD/CNRS) (2) After extensive and frustrating negotiations, we are planning to install equipment on a UK-Falkland Islands route in April 2018 (NERC) (3) Despite extensive efforts by PLOCAN, no line from Europe to S. Africa through the eastern South Atlantic is currently running, (4) Use has been made of voyages by research vessels to obtain opportunistic South Atlantic coverage (NERC). More detail is given below in summaries from individual partners.

We are in regular communications with the shipping industry and are making efforts to improve the coherence of the network and its sustainability. The following steps have been taken in this regard, and will be reported in more detail in our next deliverable on Network co-ordination:

- 1) Twelve EU countries are now members of ICOS, www.icos-ri.eu, and many of these are now reporting marine data to ICOS, which includes a number of the SOOP carbon-VOS lines. ICOS is a European Research Infrastructure with over 100 greenhouse gases measuring stations aimed at quantifying and understanding the greenhouse gas balance of the Europe and neighbouring regions, and covering ocean, atmosphere and land observations. The Ocean Thematic Centre (OTC) of ICOS is currently hosted by the Norway at the University of Bergen, and the UK will join as co-host during 2018. This will be beneficial to the SOOP, Ferrybox and VOS network with extension into the South Atlantic Ocean.
- 2) We are also liaising with JCOMM, the Joint Technical Commission for Oceanography and Marine Meteorology (www.jcomm.info). JCOMM is an intergovernmental body that provides a mechanism for international coordination of oceanographic and marine meteorological observing, data management and services to the meteorological and oceanographic communities. Discussions have commenced in early 2018, in merging the European carbon-VOS line and SOOP with the global VOS line and SOOP networks, housed under JCOMMOPS.

Detail:

Our partners have been working towards supporting and extending South Atlantic Ocean coverage of the VOS network, in order to better construct air-sea fluxes in that region with improved precision.

CNRS: Since 2015, work was underway in maintaining SOOP operations on merchant vessels in the Atlantic (North, tropical, including South Atlantic), however, due to funding cuts, this was mostly restricted to thermosalinograph data with the exception of XBTs launched from two ships in the North Atlantic subpolar gyre (lines AX01 and AX02). On two of the vessels in the tropical Atlantic, this was coupled with work on pCO₂ with our IRD partner. On the Nuka Arctica (AX01), this is linked with work on ADCP and pCO₂ from our Bergen partners. Work has been ongoing for (i) validating data from XBTs and TSGs in the subpolar gyre, (ii) maintaining/monitoring the ship network in the tropical and South Atlantic and (iii) looking at coherency between XBTs, Argo floats and ADCP along AX01. Discussions began on how to coordinate in near-real time the different operations on the VOS (Voluntary Observing Ship) Nuka Arctica. This vessel is both active in Carbon VOS and SOOP for TSG, XBTs and ADCP, and the operations involve different group partners of AtlantOS, NOAA and other US institutions. Earlier validated data has been put together to examine the combination of datasets to address key issues in ocean monitoring. In particular, how successful past monitoring was in providing coherent time variability of upper ocean heat and salinity transport and how it can be improved. Comparisons have been done from the frequent operations of SOOP and FerryBox on the ferry, Norrøna (Denmark-Iceland line, AX90).

Extension of activity in the South Atlantic has been low due to the loss of some vessels (SOOP). However, CNRS are currently in the process of identifying a ship in the Gulf of Guinea towards South Africa. There have been some interruptions to line AX01, Denmark to West Greenland, which will be interrupted until early 2018 with chartered ships afterwards and line AX02, Iceland to

Newfoundland/Maine, the ship was discontinued in January 2017 and was replaced in November 2017.

Through our ship-of-opportunity program (SSS) we are able to ensure that ships going to the South and Equatorial Atlantic were selected and properly followed (by funding a shift to iridium real time TSG data transmission, from the current INMARSAT data transmission).

Initially there were two ships selected that cross the equator, Cap San Lorenzo (Europe-Brazil) and Hawk Hunter (Europe - Gulf of Guinea area), but unfortunately the Hawk Hunter vessel has been moved to another shipping line. However, instrumentation will be left onboard the ship as it could be of some interest to our Ship of Opportunity Program (SOOP). They are currently looking for a replacement vessel. In addition, they have two other ships on the line Europe to French Guyana (MN Colibri and MN Toucan).

IRD coordinates 2 VOS lines (France-Brazil, France-French Guiana) in the Atlantic, collecting underway fCO₂, temperature and salinity data. Six voyages were successfully completed during and processed from the France-Brazil line from April to September 2015 and 2 voyages from May to October 2015 with the France-French Guiana line. After approval by the French ICOS committee, the France-Brazil line was submitted as an oceanic station to the research infrastructure ICOS (www.icos-uk.org/). During 2017, 12 voyages were successfully completed. The data collected was used in the Global Carbon Budget 2017 (Le Quere et al.). The raw data from the France-Brazil line has been submitted to the Ocean Thematic Centre (OTC) within ICOS RI and is being evaluated as part of step 2 of the labelling process. The 2017 data are still being processed and will be sent to SOCAT (www.socat.org).

A collaboration with Brazilian colleagues has allowed the extension of the CO₂ observations in the tropical Atlantic.

NERC

Measuring carbon dioxide using membrane and showerhead instruments began on the Roscoff Bay of Biscay Ferry-Box route at the start of the project. A SubCtech membrane-based instrument was compared with the General Oceanics showerhead system. Discussions began to initiate a new South Atlantic route (UK to Falkland's) with Foreland Shipping Company were extensive, as it would fill in data gaps in the South Atlantic Ocean and has a repeat route. No resolution has been made to date and discussions are still underway. An alternative South Atlantic route was pursued using HMS Protector.

We have a new SNOMS route. SNOMS (SWIRE and NOC Monitoring System) equipment was installed on a China Navigation vessel in June 2016. Hydrographic and oxygen sensors are in triplicate, with duplicate Carbon dioxide sensors in the main body of the instrument. Although this is not measuring in the Atlantic many of the procedures we are developing for quality control of Ship of opportunity data are directly applicable to AtlantOS.

A membrane comparison and underway sampling on-board the James Clark Ross on the Atlantic Meridional Transect (AMT26) cruise during 2016 was successfully completed. We have equipment to run duplicate membrane carbon dioxide sensors (pro-oceanus CV). These were run alongside the Plymouth Marine Laboratory underway system on-board the James Clark Ross ship to make the membrane/showerhead methodology comparisons. Underway samples were collected and preserved for analysis at the National Oceanography Centre (NOC). These endeavours provided carbonate data (Dissolved Inorganic Carbon, Total Alkalinity and direct carbon dioxide measurements) in the rarely sampled South Atlantic.

We have been in successful negotiations with Maersk Shipping Company to have a system running by the end of 2017 that will be from Europe to the Falklands. Maersk Raleigh will be making voyages to the Falklands at least twice per annum. There have been some delays as Maersk changed the ship operating on the Falklands route and were initially unsure if it was the best route to offer us. The tanker is on charter to the Ministry of Defence and has traditionally sailed to the Falklands via

Ascension four times per annum. They are investigating other possible shipping routes on container vessels by Maersk. Routes sail to Brazil—Argentina-Uruguay on an eight-week round trip. These ships would sail from Gibraltar to Santos, then hug the South American coast down to BA / Montevideo and then back up the coast to Pecem, before returning to Gibraltar.

During 2017-2018 we developed a system that will comprise of a flow through tank with 2 pCO₂ membrane sensors, a GTD and Turner Fluorometer, they will also have Aanderra sensors (O₂, T and S) in the lid of the tank as used on the Chin Navigate vessel the M/V Shengking (see www.snoms.info).

The National Oceanography Centre (NOC) will begin the installation of a membrane CO₂ based carbon-VOS system on MV Maersk Raleigh (April 2018) which will do a north-south Atlantic transect to the Falklands. This will have Met and Surface water measurements, e.g. 2 pro-CO₂ sensors, GTD, O₂ and T/S plus daily sampling.

We are in their 2nd year of running the Vancouver to Australia carbon-VOS with Swire on the MV Shengking (<http://www.snoms.info>). Taking similar MET and surface water measurements to the Maersk route.

NOC have also continued to contribute to the Exeter Carbon-VOS (through analysis of ancillary data over the last 15years, e.g. daily salinity samples and 4 hourly nutrient data). The PAP-SO carbon data continue to be collected (we deployed biogeochemical sensors on the frame at 1m and 30m so there are plots available on <http://projects.noc.ac.uk/pap/data/pap-april-2017>

Unfortunately, there is a slight delay on the AMT 2016 membrane sensor comparison. We are awaiting data from Plymouth Marine Laboratory. Below are examples of the PAP and SNOMS data and can be found also on their websites.

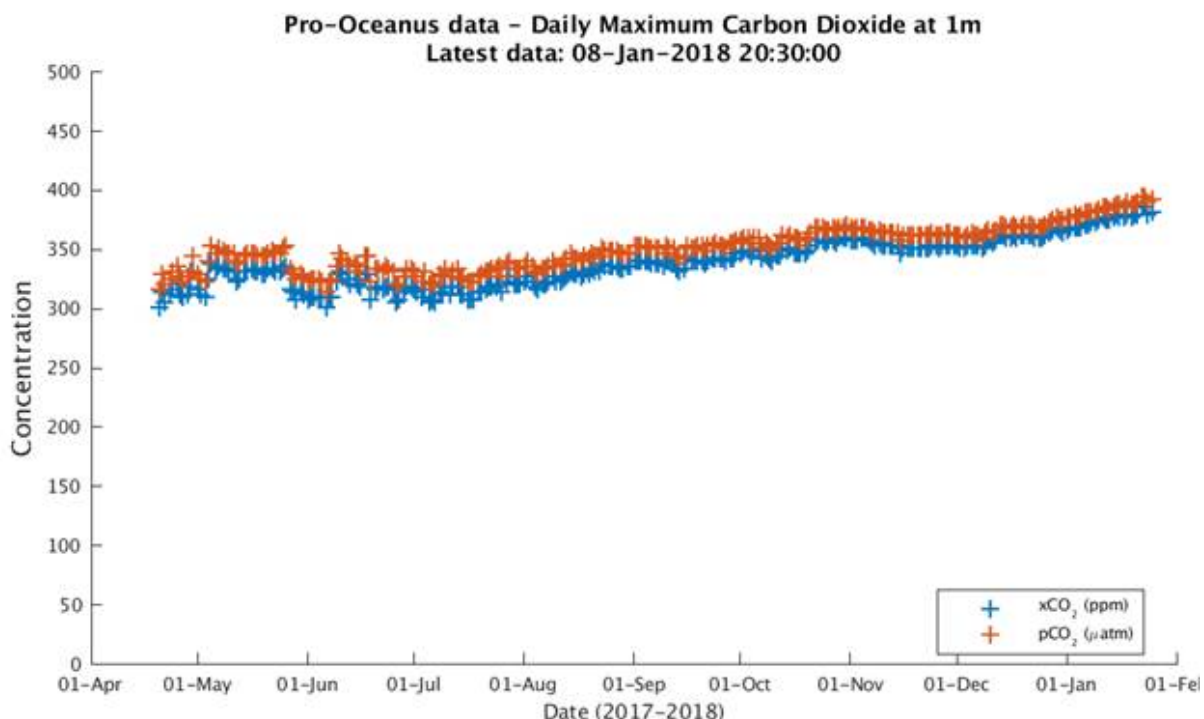


Fig. 1: PAP-SO CO₂ data from 1m (deployed April 2017 on DY077):

PLOCAN. During 2015 the QUIMA VOS line moved from the North America to Montevideo route over to a new line, from the Mediterranean Sea to Central America (Mexico and South of USA) 35°N, leaving Gibraltar to Gulf of Mexico. Discussions were ongoing with the United Arab Shipping Company and with the Marine Shipping Company in trying to locate a ship to join the North Atlantic with South Africa. PLOCAN have been experiencing difficulties in finding a ship that run for longer than 6 months.

During 2017, the QUIMA VOS line, on-board the MSC Marianna began recording data. The system was prepared to record as soon the ship left the North Sea and entering the English Channel and finishing in Valencia. All data collected has been sent to SOCAT.

The current status of the line is that it will continue running on the route from the Mediterranean Sea to Central America but uncertainty remains regarding for how long.

There are continued efforts in locating a ship that will visit the South Atlantic and there have been many discussions with the shipping company UASC. We are still awaiting news from them. The problem remains that it is difficult to find a ship that will run for longer than 6 months along this route and it remains unclear as to how long the ship will be in this East-West Atlantic route. We are also in discussion with another company that has a ship running weekly from Huelva-Spain to Gran Canaria.

VOS/SOOP Line Name	Vessel Name
AX01 Denmark – West Greenland	Nuka Arctica
France-French Guiana	MN Colibri and MN Toucan
France-Brazil	Cap San Lorenzo
UK-Falkland Islands	MV Maersk Raleigh
AX90 Denmark – Faroe Islands - Iceland	Norrøna
AX02 Iceland – Newfoundland/Maine	M/V Selfoss
Vancouver - Australia	MV Shengking
QUIMA VOS Mediterranean Sea – Central America (Mexico and South of USA)	MSC Marianna
Cape Town, South Africa – Falkland Islands	RV Meteor 133

Table showing shipping lines and vessel names currently running in the Atlantic Ocean.

(b)Improving the network instrumentation by re assessing instrument design

PML – (Participant No. 43) have been working towards improving the network instrumentation by re-assessing instrument design. At the start of the project, successful deployment established instrumentation (Dartcom system comprising head-space equilibration with non-dispersive infrared detection) during the Atlantic Meridional Transect cruise in the South Atlantic (Autumn 2015). They field-tested a prototype pCO₂ optode sensor (Aanderaa Data Instruments A.S.) in the North Atlantic during winter 2015 alongside established instrumentation. Initial results of this exercise indicated that the optode sensor gave unrealistic values for pCO₂ under the deployment conditions (Figure 3).

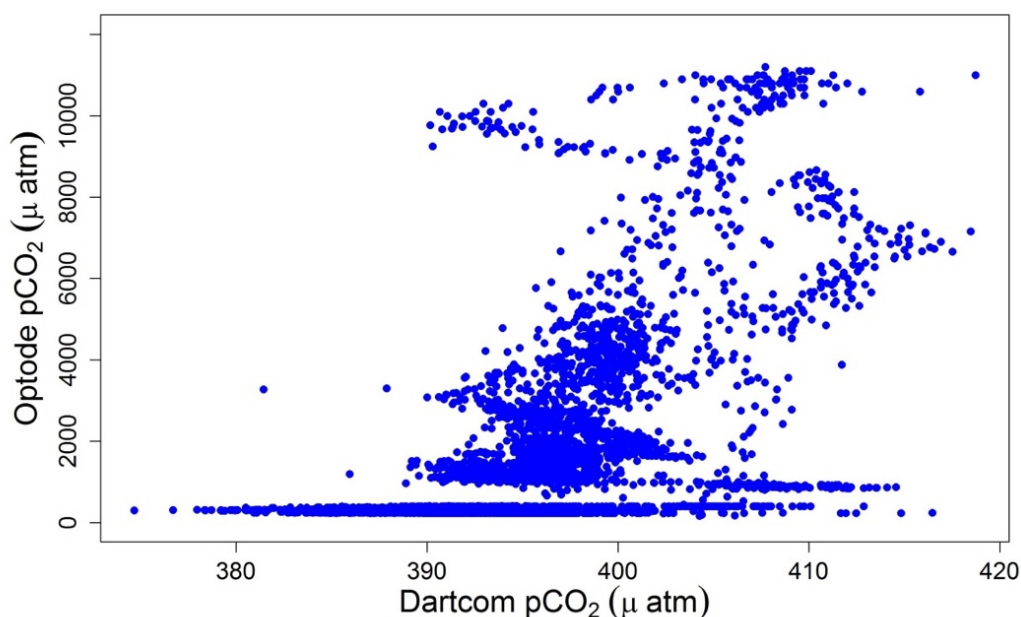


Figure 3: Initial inter-comparison of a prototype optode sensor and established instrumentation (Dartcom system).

AtlantOS has enabled ongoing discussions on sampling design, information exchange and instrumentation improvements with academia and industry at a number of forums (European Geosciences Union meeting, April 2016; Integrated Carbon Observing System Ocean Thematic Centre meeting, May 2016 and others). As a result of these discussions we are currently upgrading components of our established instrumentation (Peltier-dryer) in order to improve automation. We are also preparing a report to Aanderaa regarding our recent deployment of their prototype sensor.

During 2016-2017, PML deployed the Aanderaa Optode pCO₂ detector on two Atlantic Meridional Transect cruises (AMT26/27) alongside established pCO₂ technologies. They were 6-week cruises from the UK to the Falkland Islands, taking observations in the poorly sampled parts of the South Atlantic Ocean. The impact of changing to Optode technology is that it will achieve cost and size savings, allowing more of these instruments to be deployed worldwide. They have been processing data from a Cavity Ring Down Spectrometer (CRDS) for CO₂ and CH₄. Deployment was during the DY040 and AMT26 cruises. Data has been processed from an Aanderaa optode, deployed on DY040 cruise. The CRDS, Optode and their standard, non-dispersive infrared system (PML Dartcom Live pCO₂) are all deployed onboard the RRS Discovery, during the AMT27 cruise.

During early 2018, PML successfully deployed established standard instrumentation (Dartcom system operated by PML, comprising vented head-space equilibration with non-dispersive infrared detection) against 1) a prototype pCO₂ optode sensor (Aanderaa Data Instruments A.S.) and 2) a modified optode sensor (sensor spots from SP-CD1-D5-rMy-US, PreSens GmbH, Germany) in the North Atlantic.

Initial results of Aanderaa-PML comparison exercise show that the optode sensor compared well with the standard system under the deployment conditions (Figure 4). The calibration was stable for the period of deployment (ca. 40 days) with a 9.4 μatm RMSE (root mean square error) for residuals from the regression of optode pCO₂ against standard system pCO₂. Whilst this result is encouraging, the optode calibration requires an external reference measurement (in this case standard pCO₂). Nevertheless, the optode gives higher temporal resolution than the standard system. We plan to further develop the optode calibration algorithm and test this on existing datasets (the sensor was deployed on the Atlantic Meridional Transect in 2017; www.amt.org).

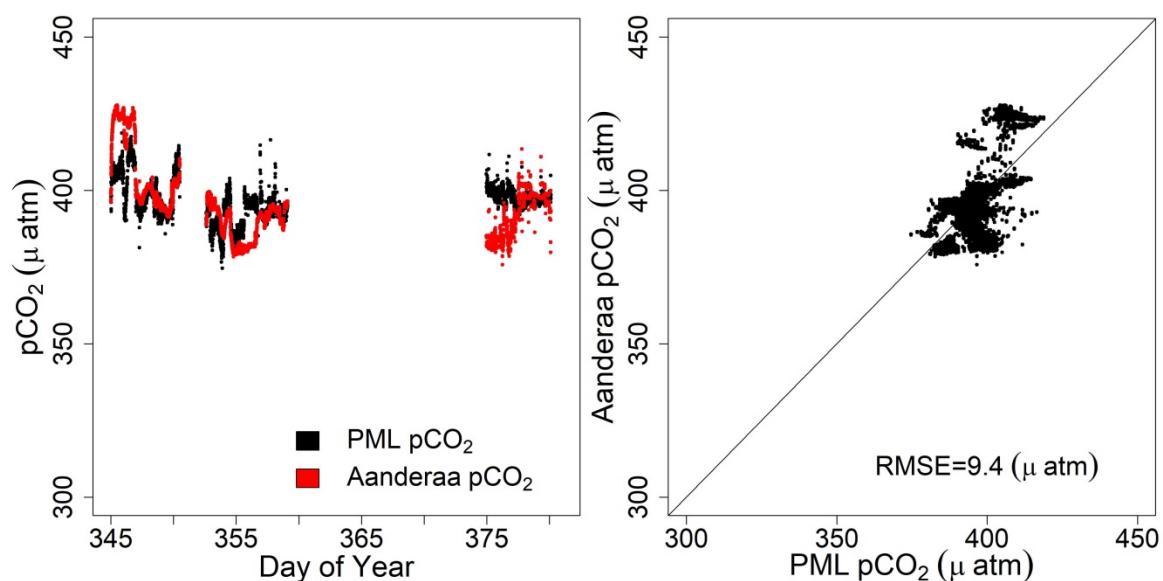


Figure 4: pCO₂ as measured with a prototype optode sensor (Aanderaa pCO₂) and established instrumentation (PML pCO₂; Dartcom system) against time in 2015 (left panel). pCO₂ from the optode sensor against the standard system (right panel; the solid line represents the 1:1 line).

The modified pCO₂ sensor was developed by the University of Southampton (UK) and National Oceanography Centre (Southampton, UK). This was compared against established standard instrumentation (Dartcom system operated by PML, comprising vented head-space equilibration with non-dispersive infrared detection). The modified optode sensor had a precision of 9.5 μatm [Clarke *et al.*, 2017]. In addition, we have extensively examined the internal consistency of our existing standard instrumentation (Dartcom system operated by PML, comprising vented head-space equilibration with non-dispersive infrared detection) as a tool for monitoring Atlantic Ocean pCO₂ and ocean acidification (OA) [Kitidis *et al.*, 2017]. This involved a detailed assessment of analytical uncertainty and consistency with other carbonate system parameters using Monte Carlo error propagation. This exercise showed that current standard instrumentation with a precision of 4 μatm can adequately constrain decadal pCO₂ and OA trends at the basin scale.

(c) The evaluation of improved EOVS carbonate systems: GEOMAR (Participant no. 1), CONTROS (Participant no. 50) and PLOCAN (Participant no. 15).

Since the start of AtlantOS, the autonomous titration system for TA has been under further development, laboratory and field testing and refinement at KM CONTROS. The system is commercially available as CONTROS HydroFIA® TA. A new PhD student began work in May 2016 for laboratory and field testing of the HydroFIA system and its deployment on an existing SOOP line in the North Atlantic (between Europe and North America).

The first full sea trial, with in situ testing and assessment exercises, took place during December 2016 – January 2017 onboard R/V Meteor 133 from Cape Town, South Africa to the Falkland Islands across the South Atlantic Ocean. The cruise featured underway (pCO₂, TA) and discrete (DIC, TA) measurements of carbonate system parameters allowing for an over-determination of the system and therefore enhanced possibilities of testing for internal consistency. Smaller field deployments out of Kiel took place prior to that.

They have developed an HPLC purification method for the indicator Bromocresol Green (BCG), application on BCG from different vendors and evaluation of its effect on the measurement performance is in progress. Further, comparison of the CONTROS HydroFIA TA underway measurements on the M133 cruise, with reference samples to evaluate the accuracy of the system is now completed. The 2nd evaluation cruise began during 3rd Nov - 14th Nov 2017 (MSM68/2) from Emden, Germany to Mindelo, Cape Verde.

Performance evaluation of the CONTROS HydroFIA® TA under semi-continuous measurement conditions to prepare the use on the North Atlantic VOS line “Atlantic Sail”. The evaluation of the data from the first big field test (M133 Cruise from Cape Town, South Africa to Port Stanley, Falkland Islands in December 2016 and January 2017) is finished. The **Results** of the precision and accuracy experiments of the CONTROS HydroFIA® TA under semi-continuous measurement conditions are as follows. A technical problem with the system on this cruise (leakage in the degasser unit) was encountered after approximately 1000 measurements. The results are given before and after this problem.

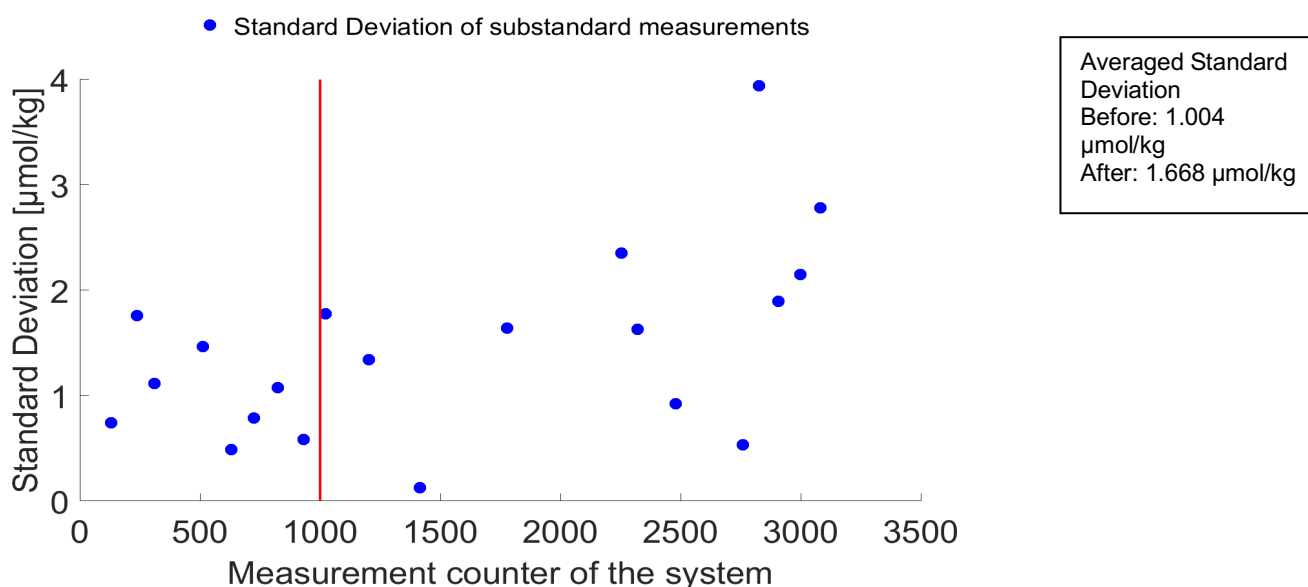


Fig. 5: Standard Deviation of substandard measurements in dependence of the measurement counter of the system. The red line denotes the time where the leakage started.

Accuracy: During the cruise discrete samples were collected in order to evaluate the accuracy of the semi-continuous underway measurements of the CONTROS HydroFIA® TA system.

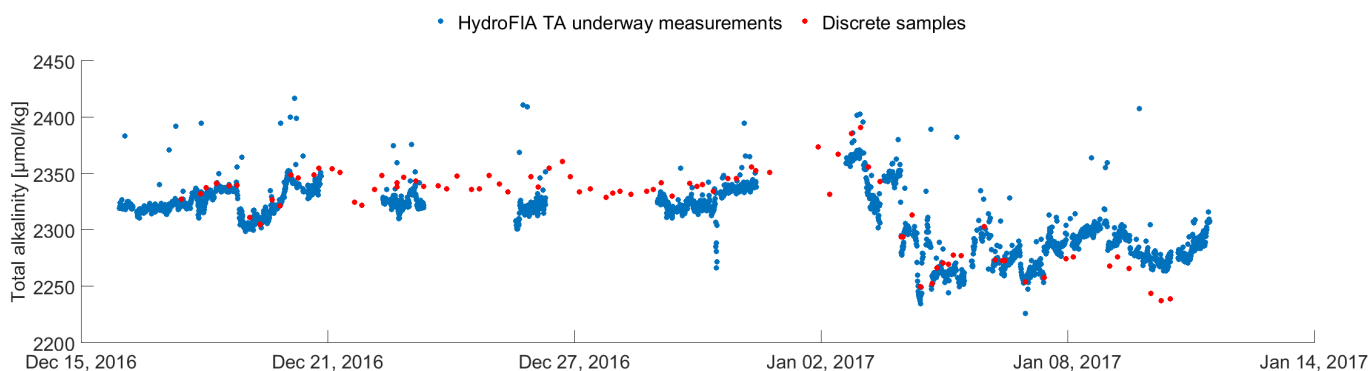


Fig. 6: Total alkalinity of the semi-continuous underway CONTROS HydroFIA® TA measurements and the discrete samples in dependence of the time.

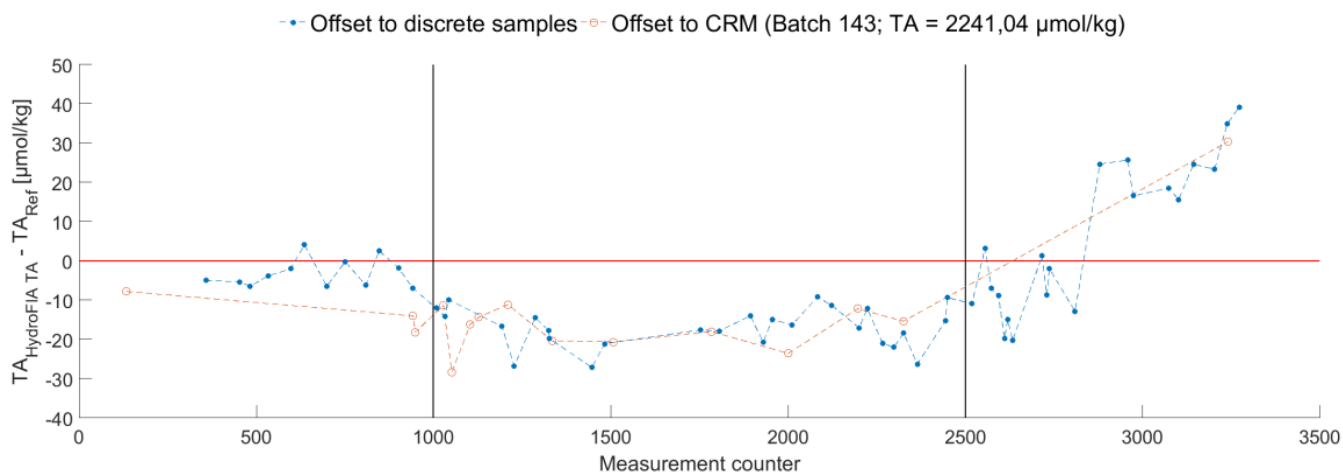


Fig. 7: Offsets of CONTROS HydroFIA® TA measurements to discrete samples (blue) respectively CRM (red) measurements.

Averaged Offset before: -5.16 µmol/kg

Averaged Offset after (between 1000 and 2500 measurements): -17.14 µmol/kg

After 2500 measurements: stepwise increase up to + 40 µmol/kg

Findings and Conclusion: The averaged precision of the system before the leakage meets the requirements of the Guide to Best Practices for Ocean CO₂ Measurements while the accuracy is higher than the optimal value. The decreasing precision and accuracy after 1000 measurements was due to leakage while the cause for the stepwise increasing offset after 2500 measurements is yet not identified. The latter might be an indication for some sort of biofouling. To meet the highest quality demands for autonomous, semi-continuous TA measurements, it seems beneficial to repeatedly monitor the precision and accuracy of the system either with discrete water samples or regular substandard measurements. For the autonomous long-term installation on the VOS line the regular substandard measurements are the favoured solution. Therefore, a stable high-volume storage of the substandard seawater has to be found. To characterize the performance of the CONTROS HydroFIA® TA system without any problems a 2nd evaluation cruise from 3rd to 14th November 2017 (MSM68/2 from Emden, Germany to Mindelo, Cape Verde) occurred. The system was modified according to the defective degasser unit encountered during the M133 cruise and also to run two TA analysers in parallel.

Integration with other work packages

DMI (Work Package 5) - DMI Infrared Radiometer activities linked to work package 2 SOOP programme.

Within AtlantOS, DMI has built up the automated collection of Fiducial reference measurement of Sea surface temperature observations from an Infrared Sea Surface Temperature Autonomous Radiometer (ISAR). The instrument has been deployed on the Smyril Line ferry: *Norrøna*, which is on a regular transit in the Atlantic between Denmark, the Faroe Islands and Iceland (AX90). The ship is also equipped with a Ferrybox system and an ADCP. The SST observations are SI traceable due to calibration procedures and protocols established within the FRM4STS project (www.frm4sts.org) and the data are now routinely used to validate the Sentinel 3/SLSTR satellite observations. Infrared radiometer network activities carried out within AtlantOS and Group for High resolution SST have led to the ESA and Copernicus funded project: "Copernicus Sentinel-3 SLSTR SST Validation using Fiducial Reference Measurements Service", which has just kicked off and will run for 1 year, with an option for another year, with participation of NOCS(lead), DMI and RAL. The project will collect radiometer observations from 3 SOOP lines in a uniform GHRSSST Data specification format (GDS2.0, www.ghrsst.org). All the data will be available on a central web page on a routine basis

together with Sentinel 3/SLSTR validation results and will thus ensure that the activities initiated within AtlantOS will continue after AtlantOS has ended.

ANNEX: Recent Publications by partners

Ibáñez J. S. P., D. Diverrès, M. Araujo, N. Lefèvre 2015. Seasonal and interannual variability of sea-air CO₂ fluxes in the Tropical Atlantic affected by the Amazon River plume. *Global Biogeochemical Cycles*, 29, doi: 10.1002/2015GB005110.

Ibáñez J. S. P., M. Araujo, N. Lefèvre 2016. The overlooked tropical oceanic CO₂ sink. *Geophysical Research Letters*, 43, doi: 10.1002/2016GL068020.

Le Quéré et al., 2015. Global Carbon Budget 2015. *Earth System Science Data*, doi:10.5194/essd-7-349-2015.

Moussa H., M.A. Benallal, C. Goyet, N. Lefèvre 2016. Satellite-derived CO₂ fugacity in surface seawater of the tropical Atlantic Ocean using a feed forward neural network. *International Journal of Remote Sensing*, vol 37, no 3, 580-598, doi: 10.1080/01431161.2015.1131872.

Gonzalez-Davila, M., Santana Casiano, J.M. & Machin, F.: Changes in the partial pressure of carbon dioxide in the Mauritanian-Cape Verde upwelling region between 2005 and 2012: *Biogeosciences*, 14, 3859-3871, 2017.

Arnone, V., Gonzalez-Davila, M. & Santana-Casiano, M.: CO₂ fluxes in the South African coastal region. *Marine Chemistry* 195 (2017) 41-49.

Ibáñez, J.S.P., Flores, M., Lefèvre, N., 2017. Collapse of the tropical and subtropical North Atlantic CO₂ sink in boreal spring of 2010. *Scientific Reports* 7, 1-9.

Lefèvre, N., Dias, F.J.S., Torres Jr, A.R., Noriega, C., Araujo, M., Castro, A.C.L., Rocha, C., Jiang, S., Ibáñez, J.S.P., 2017a. A source of CO₂ to the atmosphere throughout the year in the Maranhense continental shelf (2030'S, Brazil). *Continental Shelf Research* 141, 38-50.

Lefèvre, N., Flores, M.M., Gaspar, F.L., Rocha, C., Jiang, S., Araujo, M., Ibáñez, J.S.P., 2017b. Net heterotrophy in the Amazon continental shelf changes rapidly to a sink of CO₂ in the outer Amazon plume. *Frontiers in Marine Science*. Doi: 10.3389/fmars.2017.00278.

Kitidis, V., Brown, I., Hardman-Mountford, N., Lefevre, N., in press. Surface ocean carbon dioxide during the Atlantic Meridional Transect (1995-2013); evidence of ocean acidification. *Progress in Oceanography*, doi:10.1016/j.pocean.2016.1008.1005.

Bittig, H.C. and A. Körtzinger (2017). Technical note: Update on response times, in-air measurements, and in situ drift for oxygen optodes on profiling platform. *Ocean Sci.* 13, 1-11, doi:10.5194/os-13-1-2017.

Karstensen, J., F. Schütte, A. Pietri, G. Krahmann, B. Fiedler, B., Grundle, H. Hauss, A. Körtzinger, C.R. Löscher, P. Testor, N. Viera, and Martin Visbeck (2017). Upwelling and isolation in oxygen-depleted anticyclonic modewater eddies and implications for nitrate cycling. *Biogeosciences* 14, 2167-2181, doi:10.5194/bg-2016-34.

Dissemination and communication activities

- AtlantOS 2nd Annual Meeting, Kiel, Germany, 28-30 June 2016.
- ICDC10 International Carbon Dioxide Conference, Interlaken, Switzerland, 27-29 August 2017
- AtlantOS 3rd General Assembly Meeting, PLOCAN, Gran Canaria, Spain, 21-23 November 2017.